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“The Determination of Availability of Nitro-
genous Fertilizers in Various California
Soil Types by Their Nitrifiability”

BY

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THE DETERMINATION OF AVAILABILITY OF NITROGENOUS FERTILIZERS IN VARIOUS CALIFORNIA SOIL TYPES BY THEIR NITRIFIABILITY

By C. B. LIPMAN and P. S. BURGESS.

In the broad sense, a plant food element or compound is "available" when it is in such a form as to be soluble in the soil water in the first place and capable of being built into plant substance without harmful effects in the second place. The second of course implies the first, but the opposite is not necessarily true. Experiments have shown, moreover, that plants are not alike in their ability to use soil-water soluble nitrogen compounds; some of them must have one form, others another form, and still others are indifferent to the form and use one as well as another. Technically speaking therefore, it is only possible to obtain accurate data on the relative availability of different forms of nitrogen through the empiricism of extensive tests with every plant. Practically, however, this would appear to be quite superfluous since under soil conditions in the field as they should be maintained for normal crop production, relatively little nitrogen is present in truly "available" forms other than nitrates. For plant growth purposes therefore we are reasonably safe in assuming that the problem of nitrogen nutrition is chiefly one of supplying to the root zone enough nitrate at different parts of the life of the plant to insure normal growth. If this is assumed to be the case, and we feel justified in that assumption, then obviously the question of the relative availabilities of different nitrogenous fertilizers resolves itself into one of the rate, and the completeness of their transformation into nitrate; perhaps also in a minor way it is one of dissemination of such nitrate over the soil's internal surface.

With the foregoing ideas as a basis we have attempted first to compare under like and controlled conditions as to moisture, temperature and aeration the nitrifiability or the rate and completeness of nitrogen transformation into nitrate in a variety of nitrogenous fertilizers in any one soil, and second, to compare them in different soils, knowing as we do how soils differ in the direction indicated. We have indeed gone to the extent of determining besides nitrifiability the ammonifiability also, or the rate and completeness of nitrogen transformation in the same fertilizers into ammonia. Since, however, ammonia has a very ephemeral existence in soils and since it is so readily transformed into nitrates under normal conditions, we shall only give consideration here to the nitrifiability of the forms of nitrogen with which we have experimented.

Crop-Producing Power of a Soil as Related to its Nitrifying Power.

Before making a statement with regard to the more detailed nature of our experiments, we feel constrained to give further justification for our attitude towards the use of nitrifiability of a nitrogenous material

as a criterion of its availability to plants. A number of investigators in Europe and notably in recent years Vogel, have clearly demonstrated the relationship between the nitrifying power of a soil and its crop-producing power. It was found by Vogel for example, that in two experimental plots of the same soil and adjacent to each other, the one which had a nitrifying power in the laboratory, (so far as horn meal was concerned,) which was 50% higher than that of the other, gave an increase in beet yield of about 20% over the last mentioned plot. Similarly also when cabbage was grown the plot with the higher nitrifying power as above described surpassed the other in yield by about 30%. Similar observations were made also in this country by Lyon and his co-workers at Cornell and also by the authors whose findings in that direction will be published later. Despite the fact, therefore, that the laboratory tests of a soil's nitrifying power are carried out with materials and physical conditions quite unlike, in nature or amount, those which obtain in the field, experiment appears to have established clearly the existence of a relationship between the two which can not be seriously doubted. To be thoroughly conservative in the matter, however, we need but regard for the purposes of the work described in this bulletin, the laboratory figures as being only of relative value and not as of absolute significance. In other words, we need only assume that the relationship which obtains in a given soil under laboratory conditions with a variety of nitrogenous fertilizers will also obtain in a similar manner under field conditions and not that the amounts of nitrate produced would be absolutely the same. Similarly, with different soils, one and the same fertilizer should yield corresponding relationships. Taking together, therefore the ideas presented in this paragraph, we feel that we are conservative in the belief that availability of nitrogen in nitrogenous fertilizers as measured by their nitrifiability is of practical value in farm operations, since a strong relationship obtains between the crop producing power of a soil and its nitrifying power; also because for practical purposes, it is not so important to obtain the absolute figures for the nitrifiability of a given nitrogenous fertilizer as to obtain the value for its nitrifiability as compared to those of other nitrogenous fertilizers.

Statement of the Experiments with Methods Employed.

The basis upon which our experiments were carried out was the study of the amount of nitrate produced in one month at a constant temperature in a warm chamber of 82° F. to 86° F. from a given amount of fertilizer material thoroughly mixed with soil. In order to accomplish this object 100 gram portions of soil were employed and except as otherwise stated in the tables below, one gram of the fertilizer was thoroughly mixed with the soil in the dry state. No attempt was

made to insure the use of equal quantities of nitrogen in the case of all fertilizers tested since owing to the great diversity in the amounts of nitrogen contained in them, there was great danger of introducing physical factors of great interference into the tests. After the fertilizer and soil were thoroughly mixed in the plain glass tumbler in which they were to be incubated, enough distilled water was added to give the soil optimum moisture conditions. The tumbler was then covered with a glass plate to prevent too great a loss of moisture by evaporation and was incubated as above explained. From time to time enough water was added to the tumblers to keep the moisture conditions as nearly as possible constant in the cultures.

Twenty-nine types of soil, representing a number of the important soil regions of California, were employed with every fertilizer except as otherwise stated. The physical nature and derivation of the soils are given in the following table:

TABLE I.
Description of Soils Employed in the Experiments.

Number	Derivation	General characteristics	Total N per cent
1	Anaheim, Walnut orchard.....	Fertile sand .....	.06
2	Oakley, peach orchard.....	Fine blow sand.....	.03
3	Covina, citrus orchard.....	Fertile sand .....	.06
4	Claremont, Pomona College campus.....	Rich loam .....	.13
5	Watsonville, strawberry patch.....	Rich clay loam.....	.17
6	Berkeley, University campus.....	Fertile clay adobe.....	.11
7	Davis, grain field, University Farm.....	Fertile clay loam.....	.08
8	Holtville, grain and alfalfa land.....	Recently reclaimed silty clay.....	.03
9	Manteca, vineyard	Coarse sand .....	.04
10	Selma, vineyard	"White ash" sand.....	.03
11	Selma, peach orchard.....	"Humus poor" sand.....	.02
12	El Cajon, hay field.....	Heavy clay .....	.04
13	El Cajon, hay field.....	Infertile sand .....	.03
14	Willows, grain field.....	Heavy clay .....	.05
15	Bayliss Camp, alfalfa field.....	Alluvial silt loam.....	.09
16	Olinda	Silt loam .....	.15
17	Paradise	Humus silt loam.....	.11
18	Napa, grain field.....	Gravelly loam .....	.12
19	Crafton, citrus orchard.....	Clay loam .....	.05
20	San Fernando, citrus orchard.....	Fertile, sandy loam.....	.08
21	Ferndale	Alluvial silt loam.....	.29
22	Castroville, sugar beet field.....	Heavy silt loam.....	.06
23	Ettersburg, apple orchard.....	Humus loam .....	.25
24	Oxnard, sugar beet field.....	Fertile sandy loam.....	.10
25	Santa Paula, citrus orchard.....	Fertile gravelly loam.....	.09
26	Santa Paula, citrus orchard.....	Fertile gravelly loam.....	.08
27	Santa Paula, citrus orchard.....	Fertile gravelly loam.....	.08
28	Santa Paula, citrus orchard.....	Fertile gravelly loam.....	.07
29	Riverside, citrus orchard.....	Poor silty sand.....	.05

The variety of locations representing twenty counties in the state from which the soils described in the foregoing table were derived, is a large one, and gave opportunity of obtaining not only a great diversity as regards "lightness" or "heaviness," but also of insuring even greater variations in chemical and biological composition. This is so

because of their formation under climatic conditions, the variety of which need here only be attested to by the great range in but one phase thereof, namely the rainfall. The normal rainfall received by the Imperial Valley soil for example, is about one and one-half to two inches per year, while that for the Mattole River soil from Ettersburg, Humboldt County, is about sixty inches. Many variations are found in between these extremes. It follows necessarily that difference in soils due to such climatic variations must perforce be accompanied by differences in organic matter content of the same soils and that has been found to be the case.

The fertilizers employed included a variety of the common organic nitrogenous fertilizers and with them two inorganic materials—sulphate of ammonia and calcium cyanamid—the first a by-product of gas and coke manufacture and the second one produced by electrical processes employed for combining the nitrogen of the air with lime. A full list of the materials employed along with their percentage composition as regards total nitrogen and nitrate nitrogen are given in the following table:

TABLE II.

Description and Partial Composition of Fertilizers Employed in the Experiment.

Number	Name	Total N per cent	Mgs. nitrate N per gram of material	Remarks
1	Dried blood -----	12.29	.08	As found on market for fertilizer.
2	High grade tankage-----	9.25	.00	As found on market for fertilizer.
3	Steamed bone meal-----	3.63	1.00	17% P_2O_5 ; as on market.
4	Fish guano -----	8.47	.00	As on market.
5	Cottonseed meal -----	5.50	.00	As on market.
6	Calcium cyanamid -----	16.55	.65	As on market.
7	Sulfate of ammonia-----	21.00	.00	Baker's c.p.
8	Goat manure -----	2.46	2.50	As on market.
9	Garbage tankage -----	2.2 to 2.3	.00	As on market.
10	Apple pomace -----	-----	.00	Obtained from Hood River Valley.
11	Barnyard manure -----	1.40	Trace	Well rotted condition.
12	Green alfalfa -----	4.00	.00	Freshly cut.
13	Green kelp (Macrocystis)	1.40	.00	Freshly gathered and contained
14	Sewage sludge.*			18.7% chlorides.

*See Bull. 251, Cal. Agr. Expt. Station.

The nitrate determinations were made in accordance with the usual quantitative chlorimetric methods at the end of the incubation period. The amounts obtained in the case of every soil and of every fertilizer as indicating the degree of nitrification in all combinations are shown to best advantage in the following tables.

TABLE III.
Nitrification of Different Forms of Nitrogen in a Large Number of California Soils.

Name of fertilizer	Soil No. 1		Soil No. 2		Soil No. 3		Soil No. 4	
	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified
1. Dried blood	4.92	4.00			3.57	2.90	1.77	1.44
2. High grade tankage	3.70	4.00			3.14	3.39	25.45	27.51
3. Steamed bone meal or low grade tankage	13.30	43.89			9.59	31.65	18.37	60.62
4. Fish guano	4.0	4.72	6.88	22.70	5.84	6.89	19.37	22.86
5. Cottonseed meal	11.80	21.45	1.11	2.00	14.84	26.95	15.37	27.94
6. Calcium cyanamid					— .31		— .30	
7. Sulfate of ammonia	10.3	24.52	3.05	7.26	16.30	38.81	13.45	32.02
8. Goat manure	3.90	7.92	1.70	3.46		8.30	6.05	12.23

Name of fertilizer	Soil No. 5		Soil No. 6		Soil No. 7		Soil No. 8		Soil No. 9	
	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified	Mgs. N nitrified	Per cent of total N nitrified
1. Dried blood	8.90	7.23	22.00	17.88	15.72	12.79	2.80	2.27	— .23	
2. High grade tankage	5.70	6.16	12.70	13.73	15.00	16.21	7.15	7.73	— .08	
3. Steamed bone meal or low grade tankage	5.00	16.55	10.10	33.33	8.30	27.39	11.45	37.78	2.55	8.41
4. Fish guano	11.70	13.81	11.70	13.81	12.80	15.11	4.15	4.89	09	Trace
5. Cottonseed meal	12.80	23.27	10.70	19.45	7.80	14.18	11.15	20.27	2.65	4.81
6. Calcium cyanamid	— .13		— .20		— .12		.45	.02	— .20	
7. Sulfate of ammonia	8.50	20.23	4.10	9.76	5.00	11.90	14.65	34.89	2.00	4.70
8. Goat manure	4.10	8.30	3.10	6.23	2.40	4.89	.65	1.31	3.25	6.00

TABLE III—Continued.

Name of fertilizer	Soil No. 10		Soil No. 11		Soil No. 12		Soil No. 13		Soil No. 14	
	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified
1. Dried blood	—, 18	Trace	—, 13	—	.75	.61	—, 33	—	.68	.55
2. High grade tankage	.06	Trace	.00	—	2.40	2.59	3.25	3.51	1.95	2.10
3. Steamed bone meal or low grade tankage	1.90	6.27	—, 73	—	5.75	18.97	6.25	20.62	.25	.82
4. Fish guano	18	Trace	—, 65	—	12.80	15.11	5.63	5.90	3.50	4.14
5. Cottonseed meal	2.25	4.09	.08	Trace	11.10	26.18	5.33	9.72	1.80	3.27
6. Calcium cyanamid	—, 15	—	—, 10	—	—, 28	—	—, 27	—	—, 25	—
7. Sulfate of ammonia	1.25	2.97	.48	1.14	3.60	8.57	3.40	8.09	.80	1.90
8. Goat manure	1.40	2.84	1.85	3.74	.70	1.41	1.85	3.74	.70	1.41

Name of fertilizer	Soil No. 15		Soil No. 16		Soil No. 17		Soil No. 18		Soil No. 19	
	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified
1. Dried blood	27.15	22.07	—, 22	—	8.15	6.62	7.80	6.34	5.40	4.39
2. High grade tankage	17.25	18.64	.80	.86	7.45	8.05	7.90	8.54	2.13	2.30
3. Steamed bone meal or low grade tankage	14.25	47.02	.40	1.32	7.05	23.26	7.90	26.07	7.00	25.08
4. Fish guano	16.75	19.77	.75	.85	8.05	9.50	6.30	7.43	8.35	9.85
5. Cottonseed meal	16.25	29.54	.50	.90	6.65	12.09	6.30	11.45	12.80	23.27
6. Calcium cyanamid	—, 35	—	—, 20	—	—, 08	—	—, 03	—	—, 45	—
7. Sulfate of ammonia	6.75	16.07	.35	.83	3.85	9.16	2.90	6.90	12.60	30.10
8. Goat manure	1.15	2.80	2.85	5.77	5.45	11.07	3.00	6.07	1.20	2.43

TABLE III—Continued.

Name of fertilizer	Soil No. 20		Soil No. 21		Soil No. 22		Soil No. 23		Soil No. 24	
	Mgs. N nitrlified	Per cent total N nitrlified	Mgs. N nitrlified	Per cent of total N nitrlified	Mgs. N nitrlified	Per cent of total N nitrlified	Mgs. N nitrlified	Per cent of total N nitrlified	Mgs. N nitrlified	Per cent of total N nitrlified
1. Dried blood	15.40	12.52	27.00	21.95	30.15	24.51	.65	.52	27.32	22.21
2. High grade tankage	20.50	22.16	22.60	24.43	31.75	34.32	1.35	1.46	12.40	13.40
3. Steamed bone meal or low grade tankage	14.00	46.20	20.10	66.23	18.75	61.88	1.10	9.63	7.40	24.42
4. Fish guano	18.00	21.25	25.10	29.53	36.75	30.40	1.10	1.29	13.40	15.82
5. Cottonseed meal	19.75	35.93	17.60	32.00	24.25	44.09	1.20	2.18	11.40	20.71
6. Calcium cyanamid	— .25	—	— .05	—	— .25	—	— .50	—	— .15	—
7. Sulfate of ammonia	8.00	20.47	8.60	20.47	23.75	56.54	.95	2.26	13.40	31.90
8. Goat manure	4.10	8.33	14.10	28.65	3.25	6.00	.80	1.62	.40	.81

[illegible]

It is at once evident from an examination of the foregoing tables that there is a wide variation in the power of different soils to nitrify, under laboratory conditions, different kinds of organic nitrogen, both with regard to absolute and relative amounts of nitrate produced. Beyond this general observation it is difficult to analyze the significance of the tables without considering every nitrogenous material separately. We shall therefore take them up for discussion one by one.

Dried Blood.

It is plain from the data above submitted with respect to the nitrifiability of dried blood that the latter, so far as arid soils are concerned, can not be regarded as a "high grade" material, if availability is the criterion of quality. This is, of course, contrary to the common teaching with regard to that material. To be sure there are some soils in which dried blood has shown a relatively good availability. These soils, however, are not only in the minority, but in addition do not show dried blood nitrogen to be exceptionally available in any case.

Of twenty-nine soils tested with dried blood, eleven, or nearly 38%, transformed less than 1% of the total nitrogen present in one gram of dried blood (122 mgs. N) into nitrate in a month's incubation period at nearly optimum moisture and temperature conditions. This is significant not only because of the small percentage of the total nitrogen in the blood added, which was changed to nitrate, but because of the very small absolute amount of nitrate which is produced. It must be further noted that in many cases, of the 38% of soils which transformed less than 1% of the blood nitrogen into nitrate, there was not only no nitrate produced, but an actual loss thereof from the amount originally present in the soil, was occasioned. Of the 62% which make up the balance of the soils tested with dried blood, six, or a little over 20% of the total number, transformed between 1% and 5% of the total nitrogen present in the dried blood into nitrate. Three soils, or a little over 10%, transformed more than five and less than 10% of the total nitrogen into nitrate. Of the balance, four soils transformed more than 10% and less than 20% of the nitrogen into nitrate, four soils which changed more than 20% and less than 25% and only one soil which transformed more than 25% of the total nitrogen in dried blood into nitrate and that was only slightly more.

We thus see that about 68% of all the soils tested are incapable of rendering available more than one-tenth of the total nitrogen in the dried blood, and that most of them are far below even the 10% mark. Moreover, there are nearly 14% more of the total number of soils which fall below the limit of power to render into nitrate one-fifth of the total amount of nitrogen present, leaving only about 18% of the total number of soils which can transform more than one-fifth of the total

nitrogen present into nitrate. As noted above, in the last group of soils, the nitrifying power exceeds the 20% limit by very little, only one soil rising above the 25% limit and that but slightly.

The five soils capable of transforming more than one-fifth of the total nitrogen of the dried blood into nitrate were: Sacramento River alluvium, Ferndale alluvium, Castroville silt, Oxnard sandy silt, and Santa Paula loam (lower section 2, Teague-McKevitt Ranch). It is significant that all of these soils are well supplied with organic matter, and further that only two of the soils which were well supplied with organic matter did not stand out as good nitrifiers of blood nitrogen when compared with the other soils.

"High Grade" Tankage.

With one or two notable exceptions the soils under consideration here behave with respect to tankage nitrogen in much the same fashion as they do with respect to dried blood nitrogen. At least, the values for nitrogen transformation in tankage are of about the same order of magnitude as those for the nitrogen transformation in blood in most of the soils. Of the exceptions just noted the only really striking one is that in Soil No. 4, in which over 27% of the nitrogen of the tankage added was changed to nitrate, whereas less than 1.5% of the nitrogen of the blood was so changed in the same soil. Here, however, it must be noted that we are dealing with one of the two exceptional soils mentioned at the end of the foregoing paragraph and in this case it is no exception to the general rule. Arranging the soils in the order of their efficiency with respect to the nitrification of tankage nitrogen we obtain the following statement:

1. Five soils, or a little over 17% of the total number, either produce no nitrate or induce a loss of the soil's nitrate.

2. Ten soils, or nearly 35% of the total number transform in every case less than 5% of the total nitrogen in tankage into nitrate. In a number of cases much less than 5% is thus transformed.

Adding these first two classes together, we find that about 52% of the soils are below the 5% limit in the case of tankage as against 58% in the case of dried blood, which indicates a strong parallelism between the two materials.

3. The soils falling between the 5% and 10% limits in the case of tankage are four in number, or about 14% of the total.

4. Of the balance, five fall between the 10% and 20% limits, two between the 20% and 25% limits, and three above the 25% limit.

In general, therefore, there is a marked similarity between the nitrogen of dried blood and that of tankage from the point of view of their nitrifiability. Thus in the case of tankage, 72% of the soils, as against 68% in the case of the dried blood, are in the class which transform less

than one-tenth of the total nitrogen present into nitrate. This slight superiority of the blood is, however, more than counterbalanced by a higher percentage in the case of the tankage above the 25% limit and by the fact that the maximum transformation of organic nitrogen into nitrate in the case of tankage, is much greater than in the case of dried blood. Again the Salinas soil stands among the best nitrifiers of organic nitrogen of the type of that in dried blood and tankage. In brief, it appears from an examination of the data given for both dried blood and tankage that the latter is superior to the former from the point of view of the nitrifiability of its nitrogen, but that both forms are but poorly adapted to arid soils considered by and large.

Steamed Bone Meal or "Low Grade" Tankage.

Strikingly different from the two materials just discussed is steamed bone meal from the point of view of the nitrifiability of its nitrogen. Not only is the latter more economically changed to nitrate and in larger quantity, but it seems to be much better suited to the nitrifying processes in California soils as a whole. We may briefly summarize the data bearing on steamed bone meal in the tables, as follows:

1. In two soils only does the steamed bone meal nitrogen remain unnitrified, and only in one of these a loss of nitrate from the original soil is obtained. In the first of these, the Selma sand, the nitrifying power is extremely feeble, no matter what form of nitrogen is added. In the second soil so much nitrate is originally present from heavy nitrate applications as to discourage nitrification of all forms of nitrogen except those of cottonseed meal and sulfate of ammonia.

2. Only three soils besides the two just discussed, or about 10% of the whole number employed, transform less than 5% of the total nitrogen in steamed bone meal into nitrate.

Taking the soils under paragraphs 1 and 2 together, we find that only 17% of the total number of soils fall below the 5% limit, as against 52% in the case of the tankage, and 58% in the case of the dried blood.

3. Only two soils fall between the 5% and 10% limits with regard to the nitrogen in steamed bone meal, and only two more between the 10% and 20% limits.

4. Nine soils fall in the group between 20% and 30% limits, four soils between the 30% and 40% limits, four soils between the 40% and 50% limits, and three soils between the 60% and 70% limits.

The reversal of conditions between the steamed bone meal nitrogen and that of the two "high grade" materials previously discussed is most striking. Thus we find that whereas 80% to 90% of the soils tested have too low a nitrifying power for blood and tankage nitrogen to transform 20% of it into nitrate, about 70% of the same soils can do better than to transform 20% of the total nitrogen of steamed bone

meal into nitrate. No less striking than this is the fact that while only one soil of the twenty-nine used is capable of transforming more than one-fourth of the total nitrogen in blood into nitrate and only three of doing so in the case of tankage, there are eleven which can transform more than one-third of the total nitrogen of the steamed bone meal in that manner. The maximum point of economical transformation of nitrogen into nitrate is above 66% of the total nitrogen present in the case of steamed bone meal nitrogen while it is only half that in the case of "high grade" tankage and much less than half that figure in the case of the dried blood.

Fish Guano.

Only twenty-four soils were included in the fish guano series. Fish guano seems to be noticeably better adapted to nitrification than dried blood and tankage. This is at least true in a number of soils. In general, however, values obtained for the nitrifiability of the fish guano nitrogen resemble more those of the blood and tankage than those of the steamed bone meal and are of about the same order of magnitude. Summarizing the data for fish guano as in the foregoing cases, we find the following to be true:

1. Four soils or nearly 17% of the total number tested produce no nitrate from fish guano or induce losses of the nitrate originally present in the culture.
2. Five soils, or nearly 21% of the total number tested, transform less than 5% of the nitrogen present in the fish guano into nitrate.
3. Five soils, or about 21% of the total number tested, transform more than five or less than 10% of the nitrogen in fish guano into nitrate under the conditions mentioned.
4. Of the balance, six soils fall between the 10% and 20% limits, two between the 20% and 25% limits, and two above the 25% limit.

It is obvious, therefore, that the greatest difference between high grade tankage and fish guano is that there is a much smaller number of soils showing an availability with the latter fertilizer which falls below the 5% limit of nitrogen transformation than is the case with the first named fertilizer. This necessarily increases the number of soils in the 5% to 10% class, and in the 10% to 20% class with respect to fish guano, but it does not otherwise affect very seriously the absolute coefficient of nitrifiability of the fish guano. Beyond the 25% limit the latter exhibits characteristics very much like those of the high grade tankage. From the relative standpoint, however, as was intimated above, fish guano is superior to both dried blood and high grade tankage in its nitrifiability. Thus for example, about one-half of the soils in the case of high grade tankage transform less than 5% of the total nitrogen into nitrate, whereas the corresponding half of the soils in the

case of the fish guano fall below the 10% limit. As between dried blood, high grade tankage and fish guano therefore, the first place must be accorded the last named, the second place to tankage, and the third place to dried blood from the point of view of nitrifiability of the nitrogen in arid soils.

Here again it must be added that the humus-rich soils plainly show their superiority to the others in rendering nitrogen available in the high grade nitrogenous fertilizers. Also, as in the case of the tankage and dried blood, over 80% of the soils tested with fish guano nitrogen were found incapable of transforming more than 20% of it into nitrate.

Cottonseed Meal.

The marked superiority of the low grade over the high grade nitrogenous material in humus-poor soils which our investigations have demonstrated is nowhere more strikingly exemplified than in the figures for the nitrifiability of the nitrogen in cottonseed meal as given in the foregoing tables. Cottonseed meal clearly is to be classified with steamed bone meal in that respect but is superior even to the last named material, the good qualities of which are discussed above. Employing again the statistical method of summarizing the results obtained in the experiment the following statement may be made.

1. Not one soil of the twenty-nine tested showed a total lack of power to nitrify cottonseed meal nitrogen, though it must be conceded that in one case (Soil No. 11) only traces of nitrate were found in excess of the quantity originally present in the soil.

2. Six soils, or nearly 21% of the total number tested were found capable of transforming 5% or less of the total nitrogen of cottonseed meal into nitrate.

3. Only one soil, or less than 3.5% of the total number of soils tested, transformed more than 5% and less than 10% of the cottonseed meal nitrogen into nitrate.

4. Five soils, or about 17% of the total number of soils tested, transformed between 10% and 20% of the nitrogen in cottonseed meal into nitrate.

5. Twelve soils, or over 41% of the total number tested are capable of transforming from 20% to 30% of the total nitrogen in cottonseed meal into nitrate.

6. Three soils, or over 10% of the total number fall between the 30% and 40% limits in regard to nitrifiability of cottonseed meal nitrogen.

7. One soil transforms nearly 45% of the nitrogen in cottonseed meal into nitrate.

It is clear from the foregoing data that less than 25% of the total number of soils tested falls below the 10% limit with cottonseed meal nitrogen, and only a little over 40% fall below the 20% limit. We thus

have again a similarity between steamed bone meal nitrogen and cottonseed meal nitrogen in that about 60% or more of the soils in both cases transform more than 20% of the nitrogen into nitrate. In this respect the steamed bone meal is slightly superior to the cottonseed meal, as it is also in the case of the efficiency of the best nitrifying soil. The latter, No. 21, transformed over 66% of the nitrogen of steamed bone meal into nitrate, whereas it changed only a little over 44% of the nitrogen in the cottonseed meal into that form.

Calcium Cyanamid.

The results obtained by us with calcium cyanamid sometimes known as lime nitrogen, are not capable of discussion like the others set forth in this bulletin. Calcium cyanamid, or "lime nitrogen" is a "high grade" nitrogenous fertilizer and has only recently been produced on a commercial scale. The product used by us came from one of the European cyanamid plants and contained about 16% nitrogen and an excess of caustic lime. It was in many respects similar to other forms of lime nitrogen on the market, but different, for example, from the product of the Niagara Falls plant in that the latter contains no excess of lime. The experiments in which lime nitrogen has been tested by investigators in all parts of the world and in every conceivable manner are numerous and the literature on the subject is very voluminous. So far as we are aware, however, most of the experiments in which the calcium cyanamid was used in soil were carried out in humid regions in which organic matter is characteristically present in much larger quantities than in arid soils. In general, these investigations have not resulted in a definite appraisal, even under humid soil conditions, of the place and value of calcium cyanamid among our nitrogen fertilizers. At least they have produced so much disagreement in opinion as to give us no guide at present in the use of the fertilizer in question. Some have reported very good results with various crops when calcium cyanamid was used as a fertilizer and showed a very favorable comparison thereof with nitrate of soda and sulfate of ammonia. Others obtained diametrically opposite results and claim to have noted injurious effects of the calcium cyanamid to the crop and to the soil bacteria. To make matters more confusing for the student of the subject there is very frequently no similarity in the material employed by different investigators, no similarity in amount used, and a great divergence of soils, media, analytical methods and in many other important determinants of results.

The results obtained by us as given in Table III would seem to indicate that our soils without exception are not only incapable of nitrifying the nitrogen in calcium cyanamid, but also that the latter induces losses of nitrates from the soil's original content thereof during one

month's incubation period. In a manner these results are similar to those obtained by de Grazia, Müntz and Nottin, and several other European investigators. The experimenters named here, however, noted that when much longer incubation periods are allowed, the cyanamid nitrogen finally becomes transformed into nitrate almost completely. Thinking, also, that the amounts of calcium cyanamid employed by us were probably far too large, we repeated the experiment with three typical soils and employed instead of 1% of calcium cyanamid throughout, varying quantities as shown below. In a month's period of incubation, however, the smaller amounts of calcium cyanamid in all soils but one acted like the larger amounts. In one case, that of the Davis clay loam soil, with the smallest amount of the fertilizer used, fair nitrification was obtained. We realize, of course, that even the smallest amount of calcium cyanamid employed by us was probably ten times or more the quantity that would be employed in field practice; nevertheless, twice the quantity of sulfate of ammonia employed by us as above has yielded excellent results.

TABLE IV.

Showing Effect of Varying Quantities and Different Soils on Nitrification of Calcium Cyanamid Nitrogen.

Amount CaCN_2 used, per cent	Davis clay loam		Anaheim sand		Oakley sand	
	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified
.10	4.85	29.30	.18	1.69	.60	
.25	.65	Trace	.14	Trace	— .10	
.50	— .15		.64	Trace	— .10	
.75	— .15		.60		— .10	

In view of the foregoing table, no recommendations are made and no appraisal given by us of calcium cyanamid as a fertilizer for arid soils with the following exception. We believe it safer for the present, in view of our results and those of others, to fall back on the use of nitrogenous fertilizers whose nature and effects are better known than to employ calcium cyanamid which we have not studied thoroughly enough to understand its action. The fact that even in relatively small quantities only the Davis soil of the three tested can nitrify the nitrogen of calcium cyanamid seems to indicate again, as found by many other experimenters, that a sufficient quantity of organic matter may neutralize the poisonous effects of the fertilizer under consideration. In common with Abey, a European investigator, the writers have noted the marked production of acetylene gas in their soil cultures with calcium cyanamid, and believe that that may produce either the temporary or permanent retarding effects on the nitrification of lime nitrogen which has been variously noted, as above explained.

Sulfate of Ammonia.

Sulfate of ammonia is the second of but two inorganic sources of nitrogen which have been compared in our work with the organic sources of that element. The results obtained with it as set forth in the foregoing tables place it clearly in the same class with the low grade nitrogenous materials above discussed, from the standpoint of nitrifiability of its nitrogen in arid soils. Thus it appears to be nitrified to a degree more characteristic of steamed bone meal and cottonseed meal than of dried blood and high grade tankage. Summarizing the results obtained with sulfate of ammonia, we find the following:

1. As in the case of the cottonseed meal not one soil of the twenty-nine tested failed to nitrify sulfate of ammonia nitrogen. Indeed, the latter form of nitrogen is superior in this respect to that of cottonseed meal because in the case of one soil the latter was only very slightly nitrified as above stated, whereas definite nitrification of sulfate of ammonia nitrogen occurred in all the soils here tested without even an apparent exception.

2. Again as in the case of the cottonseed meal, six soils only fall into that class in which but 5% or less of the total nitrogen present (21% of all the soils) is transformed into nitrate.

3. According to the same criteria, however, there are six soils in the case of sulfate of ammonia, or again 21% of the total number, which fall between the 5% and 10% limits. This is in striking contrast with both cottonseed meal and steamed bone meal, the corresponding number in the first case representing only 3½% and in the second case only 7% of the total number of soils tested.

4. Five soils, or about 17% of the whole number, transformed between 10% and 20% of the total sulfate of ammonia nitrogen into nitrate. The same is true of cottonseed meal.

5. Five soils, or 17% of the whole number again fall between the 20% and 30% limits on the basis of the same criteria in the case of the sulfate of ammonia. This contrasts strikingly with nine soils in the case of the steamed bone meal, and 12 soils in the case of the cottonseed meal.

6. Again five soils, or 17% of the whole number, fall between the 30% and 40% limits in the case of sulfate of ammonia based on the same criteria which are employed for the other materials. This is not unlike the case of steamed bone meal with four soils in that category, though more unlike cottonseed meal with but three soils in that class.

7. No soils fall between the 40% and 50% limits in the case of sulfate of ammonia, but two of them transform respectively more than 56% and 57% of the sulfate of ammonia nitrogen into nitrate. This is unlike the case of cottonseed meal in which but one soil is found in the

45% class, and entirely unlike the case of steamed bone meal in which four soils are found between the 40% and 50% limits, none between the 50% and 60% limits, but three between the 60% and 70% limits.

In general, therefore, a study of the foregoing data appears to reverse the figures for nitrifiability above and below certain limits between cottonseed meal and steamed bone meal on the one hand, and sulfate of ammonia on the other. Thus in the cases of the first two materials 60% or more of the total number of soils falls above the 20% limit in the sense in which this term is used throughout this bulletin, whereas in the case of sulfate of ammonia, 60% or more of the whole number of soils fall below the 20% limit. On the other hand, sulfate of ammonia is better suited to the soils of higher efficiency which fall between the 30% and 40% limits than the other two materials just compared with it, and two soils attain a maximum efficiency with it which they do not at all approach with cottonseed meal. In that respect, however, or in point of maximum efficiency, the steamed bone meal still stands superior to all other materials with the criterion employed here throughout.

Goat Manure.*

The goat manure, like the fish guano and the calcium cyanamid, was tested in only 24 of the 29 soils. It will be noted in the tables that when judged by nitrifiability, the goat manure nitrogen cannot be regarded as an easily available source of nitrogen in most of our soils. Because, however, of the fact that it does not fail altogether to nitrify in any soil and because of one or two other interesting features about the results obtained, we give in this case as in the foregoing a statistical resume of the data obtained as follows:

1. In no soil of the twenty-four tested does the goat manure nitrogen fail entirely to nitrify.

2. In twelve soils, or in 50% of the total number tested, less than 5% of the total nitrogen added in the goat manure is transformed into the nitrate form.

3. Nine soils, or 37% of the total number tested permit of the transformation of from 5% to 10% only of the total nitrogen added in the goat manure.

4. Two soils, or a little over 8% of the total number transform, respectively, about 11% and 12% of the total nitrogen in the goat manure added into nitrate.

5. One soil, or the only one remaining, attains the extraordinary record for this form of nitrogen of transforming 28.65% of the total nitrogen of the goat manure into nitrate.

Regarding as a whole the data obtained with goat-manure nitrogen it is patent that while that material is superior to blood and tankage nitrogen in our humus-poor soils, it is distinctly inferior to the other

*The discussion under this head is submitted as a tentative one only. It is interesting but as brought out in Table V may need much modification.

materials in soils somewhat better supplied with humus. Thus for example, while no soil tested fails to nitrify goat-manure nitrogen to some degree, 87.5% of the soils tested fall below the 10% limit and nearly 96% fall below the 20% limit. In the case of blood, however, only 70% fall below the 10% limit, and only about 80% below the 20% limit. The figures are somewhat similar for high grade tankage. Compared with the steamed bone meal and cottonseed meal, however, the inferiority of the goat manure is much more marked and on the whole it must be considered a low grade nitrogen fertilizer even for our humus-poor soils. It must be added here that an element of inequality enters into the comparison of goat-manure nitrogen with the other forms above considered, owing to the fact that twice the quantity of the goat manure was employed as of the other materials. This may have caused certain physical and chemical alterations in the soil which were inimical to the activity of the agents of nitrate formation. This surmise would seem to be well justified moreover, from the following table in which are given the results obtained with three of the typical soils above used when only 1% goat manure is employed. It appears that goat manure makes a very much better showing when it is employed at the rate of 1 gram per 100 grams of soil, than when employed in twice that quantity. In fact, the difference is great enough to place it in the same class with steamed bone meal so far as the Oakley soil is concerned and with cottonseed meal in the Davis soil and the Anaheim soil, but not with steamed bone meal in the last named. It is unfortunate that the experiment could not, because of a lack of the original soils, be repeated with all the soils. But the data given in Table V indicates that the goat manure should be accorded a higher position as regards availability of its nitrogen than that indicated in Table III and in the discussion based thereon. The writers feel that those who employ goat manure in the finely ground and dry form may, in general, expect nearly as good results from it as from the other "low grade" nitrogenous fertilizers which are above discussed.

TABLE V.

Nitrification of Goat Manure Nitrogen 1% Goat Manure Employed.

	Mgs. N nitrified	Per cent total N nitrified
Davis clay loam.....	3.75	15.25
Oakley sand	5.60	22.76
Anaheim sand	6.10	24.79

Additional Experiments and Observations.

In addition to the laboratory experiments above reported, the writers have carried on, for some time, under greenhouse conditions, tests with many of the same soil types above described, in larger quantities and employing alfalfa, barnyard manure and kelp nitrogen for the nitrifiable material. The soils were mixed with the different materials and placed in pots. They were kept at nearly optimum moisture conditions throughout the experiment. Samples were drawn after three months' and after seven months' incubation and analyzed for nitrate. The barnyard-manure nitrogen and kelp nitrogen, except in Soil No. 15, not only gave no increase of nitrates in either the three or seven months' incubation period, but actually induced considerable loss of nitrate from the soil's original content thereof. Alfalfa nitrogen, on the other hand, nitrified in all the soils, though much better in some than in others.

In three typical soils, namely those from Davis, Oakley and Anaheim above described, we had occasion to test in addition to the materials above mentioned, a new form of garbage tankage now being produced in this state, and also apple pomace, a waste product from the Hood River Valley in Oregon. The latter only induced losses of nitrogen from the soils with which it was tested, but the former gave results which place it in the same class with steamed bone meal, cottonseed meal, sludge from septic tanks, and goat manure. The data are given in Table VI.

TABLE VI.
Nitrification of Nitrogen in Garbage Tankage.

	Sample I. Total N 2.3 per cent		Sample II. Total N 2.24 per cent	
	Mgs. N nitrified	Per cent total N nitrified	Mgs. N nitrified	Per cent total N nitrified
Davis -----	2.15	9.55	2.15	9.55
Oakley -----	4.70	20.90	4.30	19.10
Anaheim -----	4.60	20.40	4.60	17.70

Just what place garbage tankage would take among these materials in different soils we are not yet prepared to say, but present indications are that it will have a position between steamed bone meal and cottonseed meal in our "humus-poor" soils.

In general comment on the experiments described above, it may be added here that all cultures were run in duplicate and there was very close checking between the duplicate determinations. Only averages are given above to save space, but the complete data will be given by us in a more detailed and technical publication which will give a full discussion of many other features of our experiments which are not

cogent here, and also of the causes, so far as they are discovered or surmised, for the striking results obtained. There will also be discussed in the technical publication just referred to, the experiments of other investigators on the same subject which may be interesting in comparison with ours.

The Use of Nitrogenous Fertilizers on California Soils in View of the Experiments and Results Above Discussed.

It appears clear to the writers from the foregoing, since laboratory experiments are being well borne out by observations in the field, that the rules employed at present, for the use of nitrogenous fertilizers on our arid soils and which we have borrowed from the humid regions, must be changed. In all soils of our interior arid valleys which are not very close to stream channels or those which for other reasons are markedly deficient in organic matter, the proper bacteriological and perhaps other conditions do not obtain to render into nitrate most economically and quickly the nitrogen of high-grade organic nitrogenous fertilizers. On the other hand, conditions in those same soils are much more favorable for the nitrification of nitrogen of the low-grade nitrogenous fertilizers. Similar conditions prevail in the "humus-poor" soils of our coast valleys and of other valleys in the state in which either the soils have always been deficient in organic matter or have become depleted in that respect through excessive oxidation under favorable climatic conditions assisted by constant summer cultivation. In all such soils therefore, we would recommend the use of fertilizers as follows.

Steamed bone meal -----	1,200 lbs. per acre
Cottonseed meal -----	800 lbs. per acre
Goat manure -----	1,500 lbs. per acre
Septic or Imhoff tank sludge -----	2,000 lbs. per acre
Garbage tankage -----	1,400 lbs. per acre

If an inorganic nitrogenous fertilizer is desired, then sulfate of ammonia may be used at the rate of 250 lbs. to the acre. Nitrate of soda can also be used to advantage when it is to be obtained more cheaply than sulfate of ammonia, provided it is applied before the rains or at least before the heaviest rains have fallen.

It becomes necessary at this point to consider the nitrate fertilizers in their relations with those discussed above and in connection with their own intrinsic values for arid soils. One naturally thinks that nitrate of soda or nitrate of lime should be the most desirable of fertilizers when availability is the desideratum and this would be so were it possible to apply the nitrate and keep it in the root zone in the soil. This is not so, however, under our arid conditions since the readily soluble nitrates are quickly brought to the surface of the soil by capillarity, and as the water evaporates, are left behind in the dry soil crust into which roots do not enter. Since there is no rainfall

during a great portion of the year, and since irrigation water rises upward into the surface six inches of soil, there is little opportunity for the nitrate of the crust to redistribute itself in the deeper layers of the soil. Hence plants may suffer for want of nitrates in the root zone while those salts may be present in large quantities in the dry surface crust of the soil. Besides, other injurious effects of nitrates following upon the leaching of them from soil, which brings about more or less imperviousness, render it necessary to employ nitrate (and in the latter respect only nitrate of soda) with considerable caution, as observed above. In general, where the annual rainfall is below 20 inches per annum, nitrate should be employed only on our lighter soils, and the application should be made in the winter so as to give soaking rains a chance to distribute it thoroughly in the deeper soil layers. On the heavier soils it will probably be best not to employ it at all if large quantities must be applied or if its use is to be constant.

So far as soils rich in organic matter are concerned, or those which are in the minority in California (those well supplied with organic matter), the other organic nitrogenous fertilizers may be used if an advantage in prices, pound for pound of nitrogen, is likely to be gained.

Dried blood	400 lbs. per acre
High grade tankage.....	600 lbs. per acre
Fish guano	600 lbs. per acre

In cases in which it is desirable to apply more nitrogen in either group of soils, the same materials may be employed in larger quantities in the same proportions. Obviously, also, if phosphatic or potash fertilizers need to be employed with the nitrogenous fertilizers, they can be mixed in the necessary proportions as pointed out by us in a forerunner of this bulletin (Bull. 251, California Agricultural Experiment Station).

It appears probable also from our investigations that green manuring, together with the use of straw mulches throughout the summer in the case of our "humus-poor" soils, will in time increase their organic matter content to such a point as to enable them to transform into nitrate economically the nitrogen of the high grade organic nitrogenous fertilizers as well as that of the low grade materials.

Beyond the considerations above discussed, the choice of an individual nitrogenous fertilizer from among several suitable ones will, of course, be easy of determination since cost will be the chief item to consider. The user of fertilizers will also find it convenient, if possible, to study Table III above given and choose a fertilizer for his soil by the results obtained by us with a soil type most nearly like his. We are indeed now at work on a systematic determination of the nitrifying powers of all California soil types for typical fertilizer forms of nitrogen so that when the soils surveys of California are finally completed the reports

of them may also carry information on the nitrogen economy of every type with methods for its maintenance and ready transformation into available and assimilable forms.

Summary.

1. Field experiments are beginning to give strong evidence that relative availabilities of different forms of nitrogen in fertilizers as determined by laboratory methods in nitrification studies are reliable indices to the actual relationships which obtain between these different forms of nitrogen in field soils.

2. Such studies on relative availabilities of nitrogenous fertilizers have included above twenty-nine soil types and fourteen different forms of nitrogen, though the latter were not always tried with all soils.

3. The most ready and most economical transformation of nitrogen into nitrate is accomplished by soil flora in our soils with the so-called low grade form of nitrogen fertilizers, like cottonseed meal, steamed bone meal, goat manure, garbage tankage, and sewage sludge.

4. The so-called high grade forms of nitrogen like those of dried blood, high grade tankage, and fish guano are not well suited to most of our arid soils; dried blood giving the poorest results, tankage next, and fish guano last. Whenever soils contain a good supply of organic material and the reaction is alkaline, good results may be expected from these three materials, however.

5. Sulfate of ammonia is the most readily available of the two inorganic forms of nitrogen tested for our soils. Indeed it belongs in the same class with the low grade nitrogenous fertilizers above named, and choice between them must be based on financial considerations and on the soil's lime content very largely.

6. Statistical discussions are given above which evaluate the characteristics of every one of the fertilizers described for all soil types used.

7. Recommendations are made for the practical application of the fertilizers under consideration to our soils.

8. Many other important considerations in the nitrogen fertilizer problem in arid soils are discussed above and a preliminary statement furnished on relative values of barnyard manure, alfalfa and *Macrocytis kelp* nitrogen.

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